Work From Home and the Office Real Estate Apocalypse*

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Abstract

We show remote work led to large drops in lease revenues, occupancy, and market rents in the commercial office sector. We revalue New York City office buildings taking into account both the cash flow and discount rate implications of these shocks, and find a 49% decline in long run value. For all U.S. office markets combined, we find a $664.1 billion value destruction. Higher quality buildings were buffered against these trends due to a flight to quality, while lower quality office is at risk of becoming a stranded asset. These valuation changes have repercussions for local public finances and financial stability.

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1 Introduction

The Covid-19 pandemic led to drastic changes in where people work. Physical office occupancy in the major office markets of the U.S. fell to 10% of pre-pandemic levels at the end of March 2020, and has remained depressed ever since, creeping back to 50% by October of 2023. In the intervening period, work-from-home (WFH) practices have become ingrained, with many firms announcing permanent remote or hybrid work arrangements and shrinking physical footprints. These shifts in current and projected future office demand have led to concerns that commercial office buildings may become a stranded asset in the wake of disruptions resulting from remote work. Because office assets are often financed with debt which resides on banks' balance sheets and in Commercial Mortgage-Backed Security (CMBS) portfolios, large declines in value would have consequences for institutional investors and for financial stability.[1] The spatial concentration of office assets in urban central business districts also poses fiscal challenges for local governments, which rely heavily on property taxes levied on commercial real estate to provide public goods and services. A decline in office and adjacent retail real estate valuations may activate a fiscal "urban doom loop" that lowers the quality of life for urban residents, worsens the business climate, and leads to population loss.

This paper is the first to ask what these changes in remote work arrangements imply for the value of office buildings. To answer this challenging question, we combine new data with a new asset pricing model.

The value of office reflects the expected present discounted value of its cash flows. We begin by analyzing the shock to cash flows between the end of 2019 and the end of 2022. Using a unique data set from CompStak, we study lease-level data for 105 office markets throughout the United States over the period from January 2000 until December 2022. We document a 17.38% decrease in lease revenue in real terms between December 2019 and December 2022. Two-thirds of this decline reflects decreases in the quantity of in-force leases, the remainder is accounted for by declines in real rents. The quantity of newly-signed leases falls precipitously over this period. With more existing leases having rolled off than new leases being signed, contractual vacancy rates increased to 40-year-high levels. As of 2023.Q3, 22.1% of office space was available for rent in New York and 30.4% in San Francisco. Rents on newly-

[1] Investable commercial real estate assets were worth about $4.7 trillion at the end of 2019, of which office represents the largest component. They make up an important part of the portfolio allocation to "real assets" of a growing number of institutional investors (Goetzmann, Spaenjers and Van Nieuwerburgh, 2021). Commercial banks have about $2.4 trillion in commercial real estate loans on their balance sheets as of June 2022 according to Call Report data. Banks account for 61% of CRE debt holdings.

signed leases fell by 12.48% in real terms between December 2019 and December 2020 before reversing to pre-pandemic levels by the end of 2021, with meaningful heterogeneity across cities. Because a large fraction of leases in force at the end of 2019 did not come up for renewal in 2020, 2021, or 2022 (63.89% in the U.S., 73.35% in New York), vacancy rates are all but guaranteed to rise further in years to come, which will likely put severe downward pressure on rents.

We establish a direct connection between firms' remote work plans, measured from corporate announcements on work schedules from the data provider Scoop, and their actual reductions in leased office space. We find that firms that allow their employees to work more days from home have reduced their office space demand by more over the past three years. The same is true for firms with a larger share of remote job postings. We also find that industries and cities with more WFH exposure see larger declines in office demand.

The effects on lease revenue are not uniform across properties. We find evidence of a "flight to quality," particularly in rents. Higher quality buildings, those that are in the highest rent tier or are built more recently (informally called class A+), appear to be faring better. Their rents on newly-signed leases did not fall as much or even went up. This is consistent with the notion that firms need to improve office quality to induce workers to return to the office. In contrast, lower-quality office is affected severely both in terms of quantity of new leases and the rent levels.

Because most of the office stock is not publicly-traded (and the traded segment disproportionately consists of class A+) and sales of privately-held office properties slowed down dramatically during the pandemic, it is not possible to rely on transaction data to infer the changes that remote work wrought onto office values. To address this challenge, a central contribution of our paper is to build a novel asset pricing model to infer the changing values.

The model provides a bottom-up valuation tool, adapted to the institutional features of commercial real estate assets, but applicable more broadly. A property is a portfolio of long-term leases. The model features long lease duration, leasing risk, market rent risk, and supply growth risk. We aggregate lease revenues to the property level and subtract costs to arrive at net operating income (NOI). We discount the NOI stream with the stochastic discount factor (SDF) to obtain the property's value. The model aggregates so we can compute the value of (a segment of) the office market as a portfolio of office properties. There are two sources of aggregate risk: standard business cycle risk and aggregate uncertainty regarding the state of remote work, with stochastic transitions between a low-WFH and a high-WFH state. Rent growth, supply growth, lease renewals, new lease signings, and operating costs vary across

aggregate states.

Our main calibration exercise focuses on the New York City (NYC) office market. The model matches market rent, supply, and vacancy dynamics in the data. This includes the sharp increase in office vacancy rates since the end of 2019. The model's SDF is chosen to match the observed risk-free interest rate, the equity risk premium in the stock market (and its fluctuation across recessions and expansions), as well as the returns on a new WFH risk factor, which goes long stocks that benefit from remote work (i.e., Zoom) and goes short stocks which are hurt by it (i.e., airlines).

A key parameter that affects the change in office valuations due to WFH is the persistence of WFH practices.[2] We back out this parameter from the (unlevered) stock return on NYC-centric office REITs observed between December 2019 and December 2020. Since REITs predominantly invest in A+ office product, we conduct a separate calibration to the A+ segment of the NYC office market. The model matches the 2020 (unlevered) office return for an annual persistence parameter of 0.90, indicating that office investors believe remote-work practices to be long-lasting. We conduct sensitivity to the value of this parameter.

With this parameter in hand, we return to the full NYC office market calibration. Our main result is a 52.0% reduction in the value of the entire NYC office stock between December 2019 and December 2020. Simulating the model forward for ten years, we characterize the mean value of the office stock and—just as importantly—the uncertainty around this valuation, which depends on the sequence of shocks that hits the economy. Along the average path, office occupancy stabilizes in 2026. Since the economy returns to the low-WFH state with some probability, this mean-reversion force pushes office valuations towards an average value in 2029 that is about 49.2% below the 2019 value. Along paths where the economy remains in the high-WFH state until 2029, the office stock ends up 61.9% below its 2019 value. Hence, there is substantial uncertainty about future office values, *WFH risk*, that our approach quantifies.

We repeat the calibration exercise for San Francisco and Charlotte, the former an example of an office markets that is hit even harder by remote work and the latter an example of a market that has been more resilient. Naturally we find larger valuation reductions in the former, compared to NYC, and smaller reductions in the latter. However, both markets see declines, suggesting that spatial reallocation of activity (for example, from San Francisco to Charlotte) cannot (fully) account for our results.

What do these numbers imply for the aggregate value of the office stock? We calculate a reduction in

[2] Our notion of work from home encompasses both fully remote work and hybrid work schedules where only some days are worked from home.

value of the office stock between the end of 2019 and 2022 of $95.2 billion for NYC, $31.3 billion for San Francisco, and $1.9 billion for Charlotte. For the remaining office markets, we combine market-specific lease revenue declines with valuation ratio changes for NYC to compute the value decline. Nationwide, we find a $664.1 billion decline in office values over the three-year period.

The key takeaway from our analysis is that WFH is shaping up to massively disrupt the value of commercial office real estate in the short and medium term. This conclusion is consistent with our finding that firms appear to demand substantially less office space when they adopt hybrid and remote work practices, and that such practices appear to be persistent. We discuss the implications for financial stability, highlighting the vulnerability of regional banks, and the fiscal health of cities that rely on the tax revenues from commercial properties, highlighting the potential for an urban doom loop.

In the long run, firms may discover that the productivity or innovation impact from remote work is worse or better than expected, remote-work technologies may improve further, and cities may repurpose existing office assets to alternative use. These changes are likely to play out over decades and are beyond the horizon of our analysis. That said, our model calibration features a reduction in office supply in the WFH state, capturing reduced construction activity and adaptive reuse of office assets in the WFH state.

Related Literature Our work relates to four literatures. We relate closely to the rapidly growing literature on the measurement of remote work and its impact on real estate, surveyed in Van Nieuwerburgh (2023). Barrero, Bloom and Davis (2021); Bick, Blandin and Mertens (2023); Bartik, Cullen, Glaeser, Luca and Stanton (2020); Aksoy, Barrero, Bloom, Davis, Dolls and Zárate (2022); Brynjolfsson, Horton, Makridis, Mas, Ozimek, Rock and TuYe (2023) measure the prevalence of WFH, including with new survey instruments, tie the bulk of its growth to new work arrangements, and argue that WFH is expected to last. Rosenthal, Strange and Urrego (2021) documents a decline in the commercial rent gradient in the city center and transit cities as compared to car-oriented cities since 2020. Gupta, Mittal, Peeters and Van Nieuwerburgh (2022); Brueckner, Kahn and Lin (2023); Ramani and Bloom (2021); Mondragon and Wieland (2022) study the impact of work from home on residential real estate prices and rents. Ours is the first paper to establish the destructive impact of WFH on the valuation of commercial office properties, and to point out the ramifications for financial stability and local public finance.

An important urban economics branch of this literature explores the effects of remote work in quantitative general equilibrium models of labor and real estate markets (Delventhal, Kwon and Parkhomenko, 2022; Davis, Ghent and Gregory, 2021; Li and Su, 2021; Gokan, Kichko, Matheson and Thisse, 2022;

Monte, Porcher and Rossi-Hansberg, 2023). These models are well-suited for thinking about long-run implications of remote work on city structure, including how space could be adaptively reused. This paper uses micro data on office leases to document changes in commercial real estate markets with the rise in remote work, and uses these data as inputs in a new asset pricing model. The finance perspective, which focuses on risk and transition dynamics, is a useful complement to the urban economics perspective. An important challenge for future work is to integrate these two approaches.

Our work relates to a literature examining commercial real estate as an asset class. Cvijanović, Milcheva and van de Minne (2021); Badarinza, Ramadorai and Shimizu (2022) study the role of investor characteristics in commercial real estate. Geltner (1993) assesses valuation given existing appraised values. A key contribution of our paper to this literature lies in developing a tractable, yet rich, bottom-up model of commercial building valuation. The valuation model has broad applicability to study pricing of publicly- and privately-traded assets with cash flows stipulated in long-term, renewable contracts.

Finally, a strain of finance research has focused on identifying disruptive technological shocks to asset prices. An important topic in this literature has been that of stranded assets: whether innovation or climate change have the potential to transform existing assets into liabilities, with consequences for the creative destruction of economic activity (Gârleanu, Kogan and Panageas, 2012; Kogan and Papanikolaou, 2014, 2019; Barnett, Brock and Hansen, 2020; Pástor, Stambaugh and Taylor, 2022; Eisfeldt, Schubert and Zhang, 2023). We contribute to this literature by documenting a novel disruptive shock in the form of remote work, proposing a WFH risk factor, and highlighting exposure of urban commercial real estate assets to this risk factor.

The rest of the paper is organized as follows. Section 2 discusses changes in the office leasing market in the 2020–2022 period, highlighting the contemporaneous losses to lease revenue, and identifying remote work as the key driver. These stylized facts present key targets for the model in Section 3, which develops a novel asset pricing model to connect shocks to the office market with the valuation of office properties. Section 4 discusses the outcomes of the model for our main calibration to New York City, as well as different property segments and other geographies. Section 5 concludes with a discussion of the implications for financial and fiscal fragility. The appendix contains additional empirical results and model details.

2 The Impact of WFH on the Office Market

2.1 Data

In comparison to other real estate markets, such as residential real estate, the market for commercial office buildings is relatively opaque. We combine cash flow and pricing data from both public and private markets in order to understand the valuation of the entire office sector in light of disruptions introduced by the shift to remote work.

Our main data set is CompStak, a data platform where commercial real estate brokers exchange leasing information. The data set contains lease-level transaction data for a large sample of commercial real estate leases in the U.S. for the period January 2000–December 2022. The company sources leasing data from a large network of commercial brokerage and appraisal firms. Data coverage improves in the first part of the sample and stabilizes around 2015. CompStak leasing data separates different property types, and we focus on office leases. This comprises buildings used for conducting business activities and professional services, with space typically allocated towards administrative work, meetings, client services, and other essential building functions. Commercial office buildings comprise a distinct asset category within commercial real estate.[3]

Our data contain information on the lease, the building, and the tenant. Lease characteristics include: the execution date, lease commencement date, lease expiration date, the starting rent, the rent schedule, free rent period, tenant improvements, the size (in square feet) of the lease, floor(s) of the building, lease type (new lease, extension, expansion), and other lease options. Building characteristics include: building location, building class (A, B, or C), building age, market, and submarket. Tenant characteristics include: tenant name, tenant industry (SIC and NAICS code), tenant employees, and tenant ticker (if publicly traded). We use this data to study the evolution of the lease market over the course of the pandemic, in terms of quantities, prices, and contract features.

We augment the CompStak data with city-level vacancy information from Cushman & Wakefield. Cushman & Wakefield is one of the largest commercial real estate brokerage firms in the United States collecting information on leasing characteristics across 90 office markets. Their data track 5.6 billion square feet of office real estate by inventory, enabling comprehensive analysis of office vacancy and leasing trends across cities.

In public markets, we obtain monthly returns for office REITS included in the National Association

[3]That said, we have found very similar patterns in occupancy and rents for urban retail real estate.

of Real Estate Investment Trust (NAREIT) office index for the period 2019–2022.

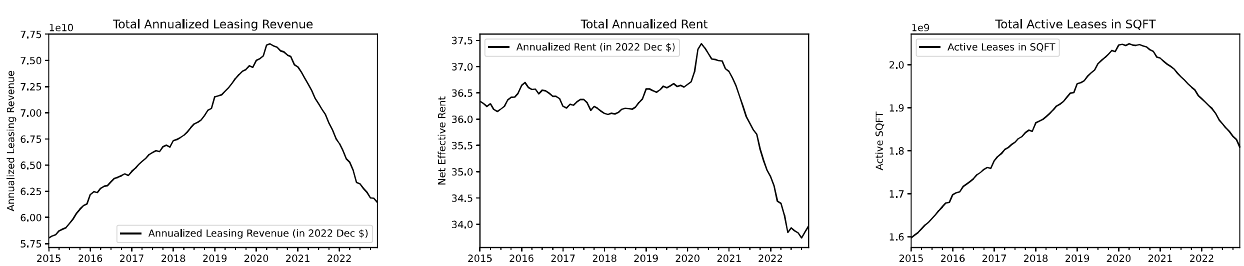
To measure remote working conditions at the firm level, we use information from Scoop, which provides a Flex Index containing information on the full time, hybrid, and fully remote working practices of over 3,000 firms with over 42 million employees. The Flex Index is the most comprehensive source on company office requirements, with information on office policies sourced from a combination of public corporate statements and crowd-sourced information by employees. This data source allows us to measure remote working plans by office tenants and connect them to their leasing decisions. This is in contrast to most survey-based approaches, which typically ask workers about their remote working status. Our focus is on firms and their space choices, so we need specialized information on working arrangements at the company level. We also explore a job postings measure drawn from Ladders, an online job search service site.[4]

2.2 Shock to Leasing Revenue

We begin by highlighting the reduction in current leasing revenue. The total value of annualized leasing revenue on *in-force* office leases across all 105 U.S. office markets was $74.35 billion in December 2019 (all numbers expressed in December 2022 dollars). Total leasing revenue experienced a 17.38% decline nationwide, falling to $61.43 billion in December 2022. This decline is substantial in light of the long-term nature of office leases. It indicates substantial shifts in leasing activity among those tenants in a position to make a choice about their office space needs. Figure 1, Panel A, plots the time series of total leasing revenue.

Figure 1: Revenues on In-Force Leases

Panel A: Revenue Panel B: Rent Panel C: Quantity



Notes: The graph shows the time series of annualized lease revenue (Panel A), rent per square foot (Panel B), and total leased space in square foot (Panel C) for in-force leases. Revenues and rent are expressed in December 2022 dollars. Data are sourced from CompStak.

[4]The platform focuses on job positions paying in excess of $100,000 a year, and so has high coverage of many remote working positions for knowledge workers. We measure the fraction of job postings which mention fully remote terms at the firm level.

This decline can be separated into the changes to rents and to quantities. Throughout the paper, we use the concept of net effective rent (NER).[5] Most leases in force in 2020–22 were signed before 2020 and have built-in nominal rent escalation clauses. However, the scheduled rent increases were not large enough to keep pace with inflation, leading to a real NER drop on in-force leases of 7.23% (Panel B of Figure 1). Also reflected in this rent decline are reductions in the NER on *newly-signed* leases. Nationally, the NER fell by 12.48% in 2020. Starting in early 2021, the NER on new leases experienced a partial reversal after accounting for geographic composition effects (see Appendix Figure A1).

The quantity of in-force leases (in square feet) fell by 10.93% between December 2019 and December 2022 (Panel C). This decline reflects (i) difficulties in filling vacant space with new tenants, (ii) lack of lease renewals by existing tenants whose lease is up for renewal, and (iii) renewals for less space than the prior lease. Figure A2 confirms a substantial decline in the volume of newly-signed leases. The evidence suggests that understanding the quantity dimension is of utmost importance when it comes to understanding shocks to office cash flows.

2.3 Physical Occupancy, Contractual Occupancy, and Lease Expiration

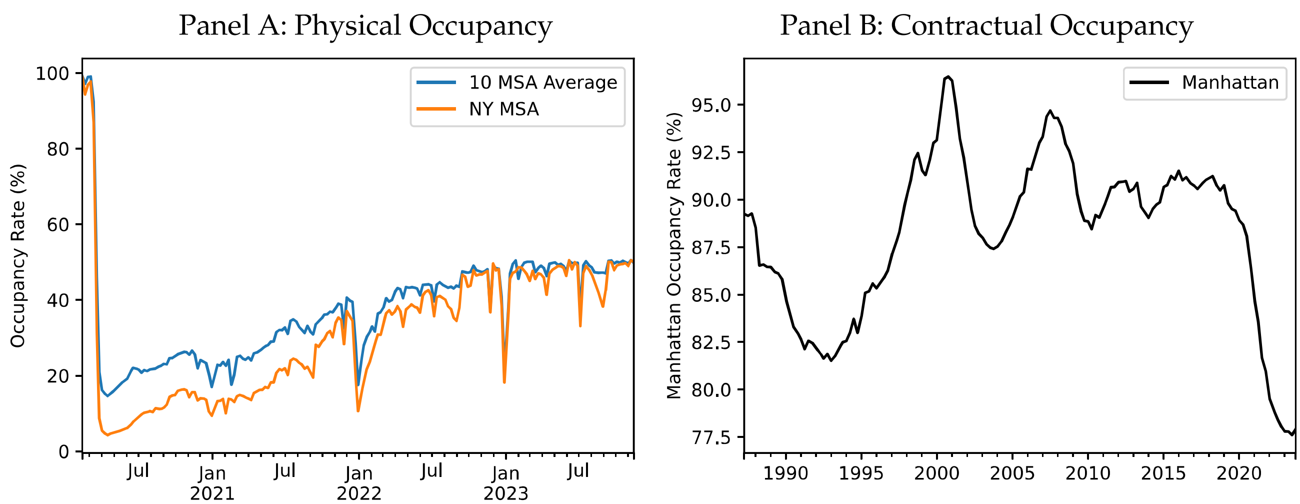
Figure 2 (Panel A) highlights the key shift which is the focus of our paper: the sudden drop in physical office presence for white-collar workers. Physical office occupancy is measured from turnstile data provided by Kastle.[6] Over the course of 2020, about 70% of college-educated workers did some or all of their work from home. In the initial wave of the pandemic, physical office occupancy rates fell to just 20% among the top-10 largest office markets (10% in NYC). Average occupancy recovered to about 30% (20%) by the end of 2020. The return to the office proceeded with fits and starts in 2021, but began to stall in mid-2022. The latest data as of November 15, 2023 show a 49.8% occupancy rate among the largest 10 office markets (50.0% in NYC). With over three years of remote work experience, many employers and employees have formed new habits and expectations. Employees report valuing the ability to WFH. Employers have revised upward their own longer-run expectations on average employee days worked

[5]The NER augments the standard contract rent schedule—a rent for each month over the course of the lease—with additional provisions including rent concessions (free rent) as well as tenant improvements (work paid for by the landlord). The resulting NER reflects the average rent earned by the landlord, and is the most relevant object in understanding changing market rent dynamics.

[6]The Kastle data cover more than 2,600 buildings in 138 cities. Other data sources, such as public transit usage, trips to the central business district from Safegraph cellphone data (Monte et al., 2023), or survey data line up well with the Kastle data. Barrero, Bloom and Davis (2023) provide a review of the literature on measuring WFH practices, finding that days worked from home account for as much as 28 percent of paid workdays among Americans 20–64 years old. Because WFH practices are concentrated among white-collar workers with the capacity to work in office settings, they have particularly large impacts on the physical presence of such workers in office buildings.

from home (Barrero et al., 2021; Aksoy et al., 2022), and have begun to adjust their demand for office space, as shown in more detail below.

Figure 2: Office Occupancy

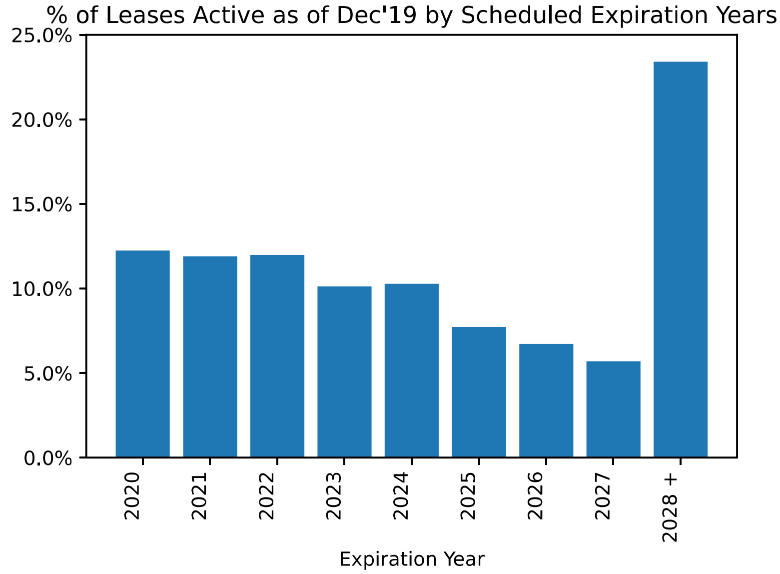


Notes: Panel A shows office physical office occupancy measured from turnstile data for the New York metropolitan area and the panel of 10 metropolitan areas covered by Kastle. Panel B shows contractual office occupancy for Manhattan, sourced from Cushman & Wakefield.

These large drops in physical occupancy did not translate into large immediate drops in commercial office cash flows, as shown above. The reason for the gradual reaction is the staggered nature of commercial leases, highlighted in Figure 3. Because most commercial leases are long-term, and not up for immediate renewal, only a fraction of office tenants have had to make active choices about their future office demand so far. Among all in-force leases as of the end of December 2019, only 36.11% by square feet came up for renewal in 2020, 2021, and 2022 combined. Nearly all of the tenants not up for renewal have continued to make rent payments, despite their lack of physical occupancy. When more leases come up for renewal in the future, the office demand of tenants who have made limited use of office space during the pandemic remains highly uncertain and is a crucial determinant of office valuation.

Despite the modest share of tenants that have seen lease expirations so far, we already observe drastically higher vacancy rates reflecting lease non-renewals and partial renewals among that sample. The contractual occupancy rate in Manhattan, the country's largest office market, was at a 40-year low of 77.8% in the third quarter of 2023, as shown in Figure 2 (Panel B). All of the evidence points to further occupancy and cash-flow declines in years to come, as more leases come up for renewal.

Figure 3: Lease Expiration Schedule



Notes: The figure shows the percentage of leases expiring per year in square feet for leases that were in force as of December 2019. Data are sourced from CompStak and are for all U.S. office markets.

2.4 Flight to Quality

Not all office is affected equally by the adoption of WFH. The highest-quality buildings, class A+, either defined as those in the top-10% of rents or those recently built, fare much better in terms of net effective rents. Indeed, our model below will confirm the lower impact of WFH on A+ office valuations.

Figure 4 illustrates this "flight to quality" by plotting the relationship between building quality and NER for all NYC and San Francisco office leases. The NER is residualized with respect to month, sub-market, and tenant fixed effects, so as to control for shifting geographic or tenant composition. Panel A sorts office properties by their rent rank, where 0.9 indicates the 90^{th} percentile of the NER distribution. We find a strong association between building quality and rents in the cross-section, consistent with the general role for filtering as in Baum-Snow and Rosenthal (2022). Interestingly, we find a steeper gradient after March of 2020. Quality becomes a more highly-valued attribute after the onset of WFH. Time series evidence in Figure A4 confirms the diverging dynamics of NER in the A+ segment versus the remaining segments (classes A-, B, and C) in both the national and NYC samples.

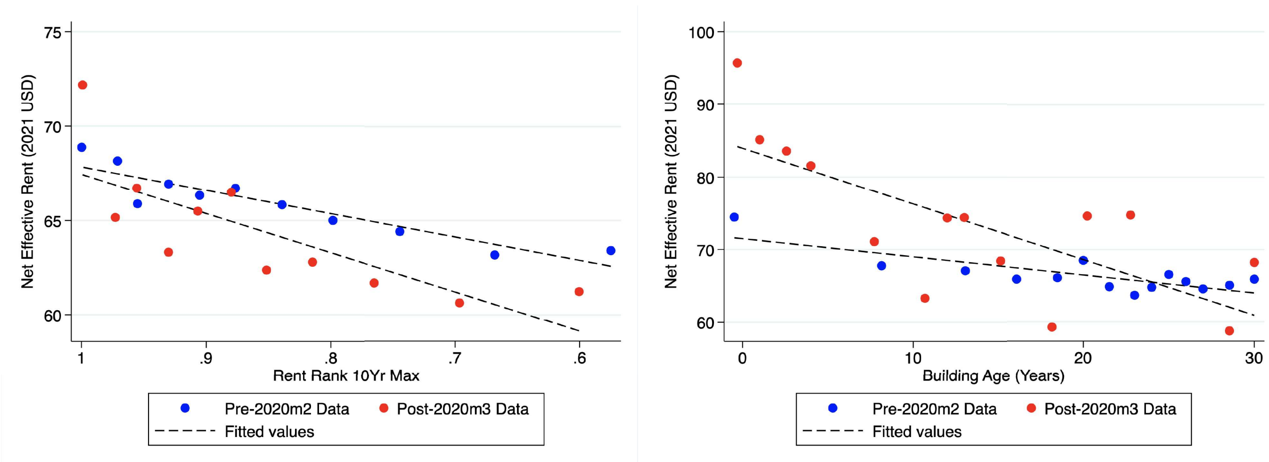
Panel B of Figure 4 sorts buildings by age rather than rent rank. Again, we find a strong NER-age gradient, which steepens after the widespread adoption of WFH. For the newest buildings, NERs are even higher after March 2020 than before. Figure A5 confirms these NER dynamics by building age.

Appendix Table A1 provides formal regression evidence estimating the negative relationship be-

Figure 4: Building Quality and Changes in Rents

Panel A: By Building Rent Rank

Panel B: By Building Age



Notes: The graph shows the changing gradients of building quality and commercial rents, before and after the beginning of the pandemic for NYC and San Francisco. Quality is measured by building building rent rank (Panel A) or by age (Panel B) and the, the highest ranking that any lease in a building had in the previous ten years. Our definition of "A+" buildings corresponds to those in the top ten percentile of this rent rank (Panel A). To estimate these specifications, we first residualize all office lease data in NYC and San Francisco against the commencement month of the lease, a tenant fixed effect, and a submarket fixed effect. We then plot the residuals from that regression (adding back the average level of rents) separately for pre-pandemic (February 2020 and before, in blue) and the post-pandemic data (March 2020 and after, in red). Data are sourced from CompStak.

tween building age and NER, after controlling for month, submarket, tenant, and even building fixed effects. We estimate an additional 3.6% point rent elasticity to age after March 2020 versus before, which is economically and statistically significant. This association is largely driven by shifts in major markets, and is particularly strong in NYC and San Francisco.

2.5 Connecting Remote Work and Office Demand

This section focuses on changes in remote work policies as a key contributor to lower office demand. Many employers have shifted to rely more on fully-remote workers, while a much larger fraction of employers have moved to hybrid work (Bloom, Han and Liang, 2022), an arrangement in which employees are expected to return to the office for some number of days in the week. The implications of hybrid work for office demand are less clear than for fully-remote positions because firms will still require an office presence. That said, firms may have the ability to stagger staff to come into the office on different days or rearrange the workspace to use it more efficiently through consolidation of multiple office locations or the use of techniques such as hot-desking, hoteling, and office neighborhoods.

We estimate remote work practices using the Scoop data which estimates firms' return-to-office plans as of the end of 2022 for a sample of over 3,000 firms. We sort these firms by the number of workdays that employees are required to be present in the office in a typical week. While return-to-office plans

remain in flux, our classification provides an estimate of firms' expected office plans at a time that they are making important choices on physical footprint. We merge tenants' WFH plans from Scoop with firm-level changes in office demand from CompStak, measured as the percentage change in active lease space in square feet from December 2019 to December 2022 across all the tenants' locations in the U.S. Tenants have a more negative change in office demand if they do not renew leases that come up for renewal during this period or if they renew and take less space.

Panel A of Figure 5 shows that hybrid work is strongly associated with lower office space demand. Firm-level office demand remains constant for firms whose employees are expected in the office 4 or 5 days per week, by 15% for tenants whose workers will be on site 2-3 days, and by 27% for tenants whose workers are expected to be in the office only 1 day per week or fully remote. Tenants have prior lease commitments that remain in force over the period over which we compute the change in office demand, so that even tenants that have gone fully or mostly remote likely have not fully adjusted their office demand by the end of 2022. These results are therefore likely to understate the long-term impacts of remote work practices on firm office demand.

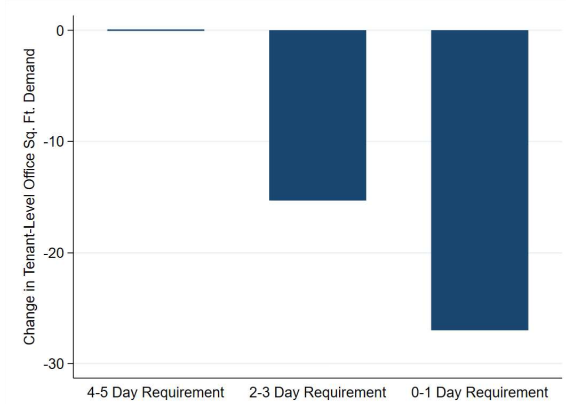
Since firm-level office demand and back-to-office plans may be measured with some error, we also examine the relationship between remote plans and office demand at higher levels of aggregation. We use the tenant industry code to aggregate both tenant office demand and WFH plans to the industry level. Panel B of Figure 5 shows a strongly negative relationship, with industries such as technology that are more remote showing much larger declines in office demand. We also examine the relationship between remote working plans and office demand at the city level in Panel C. Here, we take advantage of the fact that cities differ in their mix of industries which can be more or less conducive to remote work. We estimate the predicted number of remote working days for each city, based on each city's mix of industries and plot them against city-level estimates of changes in office vacancy from Cushman & Wakefield. While the relationship is slightly weaker than at the industry-level, we find that cities such as San Francisco which have more predicted remote work see larger decreases in overall city-level occupancy, suggesting again that remote work appears to be driving cross-sectional differences in office demand.

Table 1 provides the estimates which correspond to this figure. At the firm-level, each additional two days of remote work per week leads to a nearly 8 percentage point decline in office space (column 1).[7]

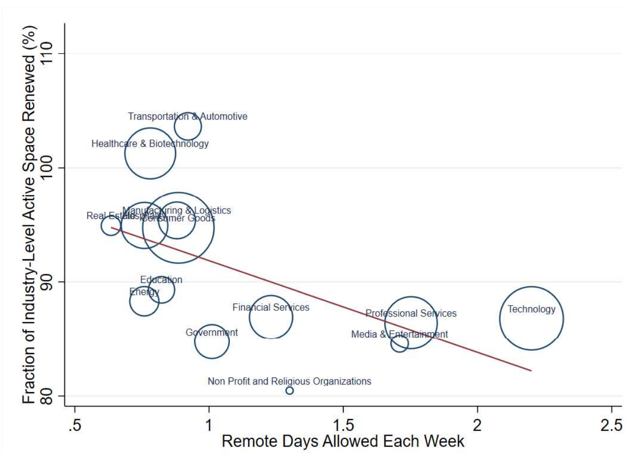
[7] The remote work index is a three point scale, so a one unit increase corresponds to an increase in two days a week remotely for a firm going from 0–1 allowable remote days to 2–3, or from 2–3 days to 4–5 days a week.

Figure 5: Hybrid Work and Office Demand

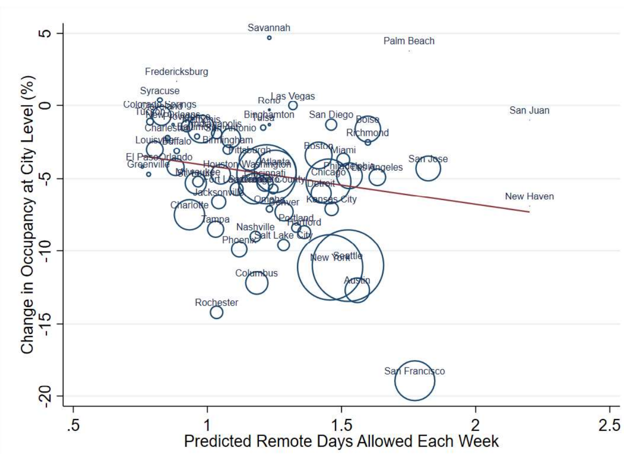
Panel A: Firm Work Mode and Office Demand



Panel B: Industry-Level Remote Work



Panel C: City-Level Predicted Remote Work



Notes: Panel A plots the relationship between firm space demand and stated back-to-work office plans. We measure firm space demand, as elsewhere in the paper, by comparing the firm's total leased square footage in December 2022 against the amount pre-pandemic in December 2019 using CompStak data. We then calculate the firm's back to office plans by using Scoop data on firm remote plans. We sort these by assessing how many days a week the firm anticipates workers being back in the office: 0–1 (close to fully remote positions), 2–3 days/week, and 4–5 days a week (including fully in person requirements). Panel B shows the relationship between industry-level remote work and industry-level firm demand, aggregating both the WFH plans and office demand to the industry level. Panel C shows the relationship between city-level remote work predicted based on the city-level industry mix and city-level change in overall occupancy level drawn from Cushman & Wakefield. We compare the occupancy ratio between 2022Q4 and 2019Q4.

We also observe this relationship at the industry and city levels, with each additional two days of remote work leading to a reduction in space demand by 14 percentage points at the industry level (column 2) and four percentage points at the city-level (column 3). In column (4), we instrument for the amount of remote work in each city based on the local industrial composition.[8] In the IV specification, we find that two additional remote work days a week results in a 21 percentage point decrease in office vacancy. This instrumental variable specification helps to address possible endogeneity and measurement problems in our baseline specification, and suggests a large causal role for remote work in driving city-level trends

[8]To construct the instrument, we replace each firm's remote work score by the average score of that firm's industry, and then aggregate to the city level.

in office demand.

Table 1: Remote Work and Office Space Demand

	OLS (1)	OLS (2)	OLS (3)	IV (4)
Remote Work Index (Firm)	-7.76			
	(13.24)			
Remote Work Index (Industry)		-14.03***		
		(3.54)		
Remote Work Index (City)			-4.30	-21.31**
			(3.45)	(8.99)
N	559	14	63	63
Industry FE	Yes	No	No	No
City FE	Yes	No	No	No

Notes: This table shows the relationship between remote work plans and change in office space demand at different levels of aggregation. In column (1) and (2), we measure change in office demand by comparing firm's total leased square footage in December 2022 against the amount leased in December 2019. Our remote work index collapses plans into three levels (4–5 days a week in person, 2–3 days a week, and 0–1 days a week). A one unit increase therefore corresponds to allowing two additional remote days a week. Column (1) shows the relationship at the firm level. Column (2) shows the relationship at the industry-level, collapsing average remote work plans and change in office demand to the industry-level. Columns (3)–(4) measure the relationship between remote work plans aggregated to the city level against city-level change in vacancy in the Cushman & Wakefield data. Column (4) instruments for the city-level remote work index using the predicted remote work level based on industrial composition. Column (1) weights observations based on office space demand of each firm, while columns (2) – (4) weight observations based on the employment share of each industry and city, respectively. Standard errors in column (1) are clustered at the city-level.

As an alternative measure of firms' WFH plans, we measure the fraction of a firm's job listings that are for fully-remote positions from Ladders. Table A2 finds a 10% point increase in the share of remote job postings lowers office demand by 3.9–4.9% points.

Combined, our empirical results show that office space demand has declined considerably over the course of the post-2020 period and that changes in remote work policies appear to be driving this trend. Firms that have low on-site work requirements or post more fully-remote job openings experience larger declines in office demand. Decreases in office demand are still substantial among firms with hybrid back-to-office plans, suggesting that even hybrid work plans pose major disruption to aggregate office demand, with significant implications for aggregate office values.

3 Office Valuation Model

How do changes in remote work and the accompanying changes in office rent revenues affect the value of office buildings? To answer this important question, we develop a valuation model. The value of a building (or portfolio of buildings or the market overall) is the expected present discounted value of

rent revenues Rev_{t+j} minus expenditures $Cost_{t+j}$:

$$\begin{aligned} V_t &= E_t\left[\sum_{j=1}^{\infty} M_{t,t+j}\left(Rev_{t+j} - Cost_{t+j}\right)\right] = E_t\left[\sum_{j=1}^{\infty} M_{t,t+j} Rev_{t+j}\right] - E_t\left[\sum_{j=1}^{\infty} M_{t,t+j} Cost_{t+j}\right] \\ &= V_t^R - V_t^C \end{aligned} \tag{1}$$

where $M_{t,t+j}$ is the cumulative stochastic discount factor (SDF) between t and $t+j$. V_t is an end-of-period (ex-dividend) price. By additivity, the value of the building is the difference between the value of the (positive) rents minus the value of the (positive) costs. This gets around the issue that the difference between revenues and costs (before-tax net cash flow) can be negative.

Several real-world complications arise regarding a property's cash flows which makes this valuation more difficult than the valuation of, say, a stock's dividend stream. Each building is a portfolio of leases with different lease terms and maturity dates. Physically identical buildings therefore have different valuations as a result of different lease structures in place. The leases are finite, but there is additional rental revenue after the leases mature. After some initial vacancy, tenant improvements, and concessions (e.g., free rent) the space will be released at the market rent. Furthermore, the building may not be fully leased, in which case vacancy creates cash flow shortfalls. Hence, the key sources of risk are vacancy risk and market rental risk. On the cost side, the operating expenses include the reserve account to provision for regular capital expenditure or maintenance. A part of the costs is fixed, while another part is variable (with occupancy). The fixed costs create operational leverage. Costs also include leasing commissions, which are different for new leases and lease renewals. Finally, there is the risk of supply growth.

The model we propose includes most of these real world features in a tractable way. It can be used to value an individual building, or a (sub-)market, which is a portfolio of buildings. The full derivation of the model is in Appendix C. This model should be useful for valuing income-generating properties in any sector or location more broadly. Section 3.3 describes a model calibration focused on the NYC office market.

3.1 Modeling Revenues

The central challenge in modeling leases is incorporating the process of lease expiration and renewal. This is important because commercial leases are long-term in nature, but have shorter duration than the expected life of the building. In our model, leases comes due in the current period with probability χ. Under the law of large numbers, χ is also the share of all leases coming due in a given period. The

random arrival of lease expiration absolves us from having to keep track of the history of past lease executions.

Let Q_t^O be the occupied space (in square feet), Q_t^V the vacant space, and $\overline{Q}_t$ the total size of the building/market at the end of period t. Then $Q_t^V = \overline{Q}_t - Q_t^O$. The law of motion for occupied space in a building/market is:

$$Q_{t+1}^O = \min\left\{Q_t^O(1-\chi) + Q_t^O \chi s_{t+1}^O(z') + (\overline{Q}_t - Q_t^O)s_{t+1}^V(z'), \overline{Q}_{t+1}\right\}.$$

The first term denotes the space that was occupied at the end of last period which is not up for renewal. The second term denotes the space that is up for renewal, a share $0 \leq s_{t+1}^O(z') \leq 1$ of which is being renewed. The renewal rate $s_{t+1}^O(z')$ is a stochastic process whose realized value depends on the state of the world z' in period $t+1$. It combines the extensive margin of renewal (the share of space that gets renewed versus not-renewed) and the intensive margin (the share of space in square feet which is renewed conditional on renewal). The third term denotes space that was vacant at the end of last period and is being newly rented. The stochastic process $0 \leq s_{t+1}^V(z')$ is the share of office space that was vacant which is being newly rented out in period $t+1$ in state z'. This term includes the part of lease expansions that exceeds the original space (renewals for more space). This share is not bounded from above by 1, to allow for growth in a building/market due to changes in the supply. The minimum operator guarantees that space occupancy in a building/market is weakly below available supply.

The growth in available space in a building/market, which reflects new construction (renovation of a building that adds floor space or new construction in a market) net of depreciation, follows the stochastic process:

$$\frac{\overline{Q}_{t+1}}{\overline{Q}_t} - 1 = \eta_{t+1}(z').$$

We define the occupancy rate $\widehat{Q}_t^O = \frac{Q_t^O}{\overline{Q}_t}$, with law of motion:

$$\widehat{Q}_{t+1}^O(\hat{Q}_t^O, z') = \min\left\{\frac{\widehat{Q}_t^O(1-\chi) + \widehat{Q}_t^O \chi s_{t+1}^O(z') + (1-\widehat{Q}_t^O)s_{t+1}^V(z')}{1+\eta_{t+1}(z')}, 1\right\}. \tag{2}$$

The rent revenue in a building/market in period $t+1$ takes the following form:

$$Rev_{t+1} = Q_t^O(1-\chi)R_t^O + \left[Q_t^O \chi s_{t+1}^O(z') + (\overline{Q}_t - Q_t^O)s_{t+1}^V(z')\right] R_{t+1}^m$$

in which R_t^O is the average net effective rent per square foot on existing leases and R_{t+1}^m is the market's net effective rent (NER) per square foot on newly executed leases. The NER incorporates concessions (free rent) and tenant improvements. We assume that all new leases are signed at the market NER.

The growth rate of the market's NER per square foot follows the stochastic process:

$$\frac{R_{t+1}^m}{R_t^m} - 1 = \epsilon_{t+1}(z').$$

We define the relative rent $\widehat{R}_t^O = \frac{R_t^O}{R_t^m}$, with law of motion:

$$\widehat{R}_{t+1}^O = \frac{(1-\chi)\widehat{R}_t^O}{(1+\varepsilon_{t+1}(z'))(1+\eta_{t+1}(z'))}\frac{\widehat{Q}_t^O}{\widehat{Q}_{t+1}^O} + \left[\chi s_{t+1}^O(z')\frac{\widehat{Q}_t^O}{\widehat{Q}_{t+1}^O} + \frac{1-\widehat{Q}_t^O}{\widehat{Q}_{t+1}^O}s_{t+1}^V(z')\right]\frac{1}{(1+\eta_{t+1}(z'))} \tag{3}$$

Define potential rent as the rent revenue based on full occupancy at the prevailing market rent: $\overline{Q}_t R_t^m$. Denote the rent revenue scaled by last period's potential rent with a hat:

$$\widehat{Rev}_{t+1}(\widehat{Q}_t^O, \widehat{R}_t^O, z') = \frac{Rev_{t+1}}{\overline{Q}_t R_t^m} = (1-\chi)\widehat{Q}_t^O\widehat{R}_t^O + \left[\widehat{Q}_t^O\chi s_{t+1}^O(z') + (1-\widehat{Q}_t^O)s_{t+1}^V(z')\right](1+\epsilon_{t+1}(z')).$$

Recall the expected present discounted value (PDV) of lease revenues V_t^R from (1). Scale this PDV by potential rent to obtain a valuation ratio: $\hat{V}_t^R = \frac{V_t^R}{\overline{Q}_t R_t^m}$. This "price-dividend" ratio of the lease revenue claim solves the Bellman equation:

$$\hat{V}_t^R(\widehat{Q}_t^O, \widehat{R}_t^O, z) = \sum_{z'}\pi(z'|z)M(z'|z)\left\{\widehat{Rev}_{t+1}(\widehat{Q}_t^O, \widehat{R}_t^O, z') + (1+\eta(z'))(1+\epsilon(z'))\hat{V}_{t+1}^R(\widehat{Q}_{t+1}^O, \widehat{R}_{t+1}^O, z')\right\} \tag{4}$$

subject to the laws of motion for the scaled state variables (2) and (3).

3.2 Modeling Costs

On the cost side, there are three types of costs: operating expenditures, capital expenditures, and leasing commissions. Note that tenant improvements and concessions (free rent) are already reflected on the revenue side since we consider net effective rent as our rent concept.

We fold the per-period equivalent of capital expenditures into the operating expenses, a common practice (the capital reserve account). These per-period capital expenditures are independent of building occupancy. Other operating costs that are independent of occupancy are property insurance, property taxes, and the fixed part of utilities and maintenance. We refer to these combined fixed costs per square

foot as C_t^{fix}. Utilities and maintenance also contain a variable component that depends on building occupancy. Variable costs per square foot are denoted as C_t^{var}. Finally, leasing commissions (broker fees) capture costs associated with bringing in new tenants. Leasing commissions are higher for new leases than for renewals: $LC^N > LC^R$. Commissions are variable costs, proportional to the first-year rental revenue from the lease.

Adding the costs associated with fixed and variable expenses, along with broker commissions, yields an expression for total building costs:

$$Cost_{t+1} = C_{t+1}^{var}(z')Q_{t+1}^O + C_{t+1}^{fix}(z')\overline{Q}_{t+1} + \left[Q_t^O\chi s_{t+1}^O(z')LC_{t+1}^R(z') + (\overline{Q}_t - Q_t^O)s_{t+1}^V(z')LC_{t+1}^N(z')\right]R_{t+1}^m.$$

We scale costs by lagged potential rent:

$$\begin{aligned}\widehat{Cost}_{t+1} &= \frac{Cost_{t+1}}{\overline{Q}_t R_t^m}\\ &= c_{t+1}^{var}(z')\widehat{Rev}_{t+1} + \left[c_{t+1}^{fix}(z')\widehat{R}_{t+1}^O(1+\eta(z')) + \hat{Q}_t^O\chi s_{t+1}^O(z')LC_{t+1}^R(z') + (1-\hat{Q}_t^O)s_{t+1}^V(z')LC_{t+1}^N(z')\right](1+\epsilon(z'))\end{aligned}$$

where cost per square foot scaled by effective rent per square foot are defined by lowercase letters:

$$c_{t+1}^{fix}(z') = \frac{C_{t+1}^{fix}(z')}{R_{t+1}^O} \quad and \quad c_{t+1}^{var}(z') = \frac{C_{t+1}^{var}(z')}{R_{t+1}^O}.$$

Recall the expected PDV of costs V_t^C from (1). Scale this PDV by potential rent to obtain a valuation ratio: $\widehat{V}_t^C = \frac{V_t^C}{\overline{Q}_t R_t^m}$. This "price-dividend" ratio of the cost claim solves the Bellman equation:

$$\widehat{V}_t^C(\widehat{Q}_t^O, \widehat{R}_t^O, z) = \sum_{z'} \pi(z'|z)M(z'|z)\left\{\widehat{Cost}_{t+1}(\widehat{Q}_t^O, \widehat{R}_t^O, z') + (1+\eta(z'))(1+\epsilon(z'))\widehat{V}_{t+1}^C(\widehat{Q}_{t+1}^O, \widehat{R}_{t+1}^O, z')\right\} \tag{5}$$

subject to the law of motion for the scaled state variable in (2).

3.3 Calibration

Since we are interested in understanding how the value of office is affected by remote work, we calibrate the model to the entire stock of office. While risk and return vary across space, our initial focus is on NYC, America's largest office market. One key parameter will be identified from the A+ segment of the NYC office market, so we also need a separate calibration for that segment of the office market. Section

4.3.1 conducts the calibration exercise for two more cities, San Francisco and Charlotte, the former an example of a city affected more severely by WFH than NYC, the latter an example of a city affected less.

3.3.1 States and State Transition Probabilities

The state variable z follows a Markov Chain which can take on four values: expansion (E), recession (R), WFH expansion (WFH-E), WFH recession (WFH-R). Here, WFH stands for a world where a substantial amount of work is done remotely or in hybrid format. Before 2020, the world was oscillating between the E and R states.[9]

The model is calibrated at an annual frequency. We decompose the 4×4 annual state transition probability matrix as the Kronecker product of two 2×2 transition probabilities. The first matrix governs the dynamics between expansions and recessions. The second one governs the dynamics between the low-WFH and high-WFH states. These two components are assumed to be independent:[10]

$$\pi(z'|z) = \pi^{BC}(z'|z) \otimes \ \pi^{WFH}(z'|z).$$

We calibrate expansions and recessions to the observed frequency of NBER recessions in the 1926–2019 data, and the average length of a recession. Recessions are shorter-lived than expansions. This pins down the 2×2 matrix $\pi^{BC}(z'|z)$:

$$\pi_{BC} = \begin{array}{c c} & \begin{array}{cc} E & R \end{array} \\ \begin{array}{c} E \\ R \end{array} & \begin{bmatrix} 0.879 & 0.121 \\ 0.563 & 0.437 \end{bmatrix} \end{array}.$$

The WFH transition matrix is a key object in our valuation exercise. We set the probability of entering the high-WFH state from the low-WFH state equal to $q = 5\%$, to capture the idea that a transition to mass adoption of remote work was unlikely before 2020.[11] The second parameter is the probability of

[9] We think of the E and R states as states where a small amount of work was done from home, and refer to these states as low-WFH states. American Time Use Survey data for 2017 put the fraction of remote work at around 5%. Conceptually and computationally, the model can easily accommodate more remote work states. However, this results in a parameter proliferation that complicates calibration.

[10] The model can accommodate correlation between the components. However, such correlation is difficult to measure based on the short experience with the high-WFH state. There are opposing economic forces. On the one hand, a recession may result in more bargaining power for employers that want employees to return to the office. On the other hand, a recession may result in lower demand for office in an effort to cut costs, boosting WFH. Therefore, zero correlation seems like a natural compromise.

[11] The underlying reason may be a coordination failure. There was no incentives for individual employees or firms to deviate from the low-WFH equilibrium. The pandemic forced the economy into the high-WFH equilibrium. The return to the low-WFH equilibrium may fail when agglomeration benefits are large, since there are low incentives to return to the office when other employees or firms are not in the office either. Monte et al. (2023) provide compelling empirical and theoretical evidence of the presence of this low-WFH and high-WFH multiple equilibrium problem. They argue large cities have been stuck in the high-WFH equilibrium for the past several years. Our model captures uncertainty about this transition.

remaining in the WFH state conditional on having entered it, which we label p. The latter governs the persistence of remote work, and it is a key parameter of interest in the paper. We will infer the value of p from the observed change in class A+ office valuations at the onset of the pandemic, as measured from office REIT data, and perform robustness with respect to this parameter. As explained below, this calibration delivers $p = 0.8969$. These two parameters pin down $\pi^{WFH}(z'|z)$:

$$\pi_{WFH} = \begin{array}{r} \\ \text{low-WFH} \\ \text{high-WFH} \end{array}\!\!\begin{array}{c} \begin{array}{cc} \text{low-WFH} & \text{high-WFH} \end{array} \\ \begin{bmatrix} 1-q & q \\ 1-p & p \end{bmatrix} \end{array} = \begin{array}{r} \\ \text{low-WFH} \\ \text{high-WFH} \end{array}\!\!\begin{array}{c} \begin{array}{cc} \text{low-WFH} & \text{high-WFH} \end{array} \\ \begin{bmatrix} 0.95 & 0.05 \\ 0.1031 & 0.8969 \end{bmatrix} \end{array}.$$

3.3.2 State Prices

The one-period SDF takes the form $M(z'|z)$. We decompose this SDF into a pre-WFH SDF and a WFH shifter:

$$M(z'|z) = M^{BC}(z'|z) \otimes M^{WFH}(z'|z).$$

We choose $M^{BC}(z'|z)$ to match the risk-free rate and the equity risk premium in both expansions and recessions. First, we match the risk-free rate, conditional on being in a given state:

$$R_t^f(z) = \left(\sum_{z'} \pi^{BC}(z'|z) M^{BC}(z'|z) \right)^{-1}.$$

We average the observed 3-month T-bill rate in excess of inflation in expansions and recessions using pre-2020 data. Second, we match the average return on equity in excess of inflation conditional on each pair (z, z'). We impose the conditional Euler equations for the aggregate stock market return Ret^{mkt} in each state $z = E, R$:

$$1 = \left(\sum_{z'} \pi^{BC}(z'|z) M^{BC}(z'|z) Ret^{mkt}(z'|z) \right)$$

Combined, the equations for the risk-free rate and the equity return provide four equations in four unknowns, and hence pin down $M^{BC}(z'|z)$:

$$M^{BC} = \begin{array}{r} \\ E \\ R \end{array}\!\!\begin{array}{c} \begin{array}{cc} E & R \end{array} \\ \begin{bmatrix} 0.757 & 2.776 \\ 0.322 & 1.791 \end{bmatrix} \end{array}.$$

The model matches the observed long-term average real risk-free rate of 0.5%. It implies a higher real risk-free rate in recessions than in expansions. The model also matches the historical average equity re-

turn of 11.1%. The equity risk premium is 10.5% unconditionally, and substantially higher in recessions (28.2%) than in expansions (6.7%).

The SDF component $M^{WFH}(z'|z)$ governs how the risk associated with working from home is priced. It is chosen to price the returns on a portfolio of stocks that goes long companies that benefit from remote work and short companies that are hurt by remote work. We deliberately exclude real estate stocks from the portfolio. We call this portfolio the WFH equity factor. Appendix B details the construction of the WFH return, shows how we estimate its market price of risk from the cross-section of office REIT returns, and explains how we calibrate M^{WFH} in order to satisfy the Euler equation for the WFH factor.

Finally, since we want the risk-free rate to be fully determined by $M^{BC}(z'|z)$ and unaffected by M^{WFH}, we scale each row of $M^{WFH,unsc}$ such that $E[M^{WFH}|z]$ is equal to 1 for each state z:

$$M^{WFH,unsc} = \begin{array}{r} \\ \text{low-WFH} \\ \text{high-WFH} \end{array} \begin{array}{c} \begin{array}{cc} \text{low-WFH} & \text{high-WFH} \end{array} \\ \begin{bmatrix} 1 & 1.696 \\ 1 & 1.696 \end{bmatrix} \end{array}, \quad M^{WFH} = \begin{array}{r} \\ \text{low-WFH} \\ \text{high-WFH} \end{array} \begin{array}{c} \begin{array}{cc} \text{low-WFH} & \text{high-WFH} \end{array} \\ \begin{bmatrix} 0.966 & 1.639 \\ 0.616 & 1.044 \end{bmatrix} \end{array}.$$

The negative market price of WFH risk we estimate implies that cash flows in the high-WFH state are more valuable, as shown in the second column of the left matrix. High-WFH states are bad states of the world, high marginal-utility states for the representative agent. Our inference from equity markets is consistent with the inference in Monte et al. (2023) from a structural urban model, who argue that the shift to more WFH reduced aggregate welfare.[12] To understand the quantitative importance of priced WFH risk, we will conduct a robustness check where we set M^{WFH} to a matrix of ones.

In sum, the asset pricing model pins down the risk-free rate and contains two priced aggregate risk factors: an equity market and a WFH factor.

3.3.3 Office Cash Flows for All NYC

Since we are interested in valuing the entire commercial office stock in New York City (All NYC), our main calibration is for the office stock of the entire city. We consider a second calibration to the A+ segment. The calibration algorithm is detailed in Appendix D.

We set the lease expiration parameter at $\chi = 0.14$. This delivers a lease duration of 7.22 years, matching the CompStak average office lease term in the NYC data. Table 2 lists the remaining parameters.

[12] In Monte et al. (2023), aggregate productivity is lower in the high-WFH state. In contrast, in Davis et al. (2021) and Delventhal et al. (2022) aggregate productivity is higher. However, even if the high-WFH state is positive for productivity, it may require higher investment, which can result in higher marginal utility of consumption (Papanikolaou, 2011).

Table 2: Calibration for All NYC

Variable	Symbol	E	R	WFH-E	WFH-R
Market NER growth	ϵ	0.0574	-0.1167	0.0194	-0.1593
Supply growth	η	-0.0142	-0.0147	-0.0291	-0.0296
Lease renewal share	s^O	0.8573	0.3770	0.4346	0.1911
New leasing share	s^V	0.1790	0.3053	0.0907	0.1548
Fixed cost/rent ratio	c^{fix}	0.2000	0.2000	0.2000	0.2000
Variable cost/rent ratio	c^{var}	0.2300	0.2300	0.2300	0.2300
Leasing commission new	LC^N	0.3000	0.3000	0.2400	0.2400
Leasing commission renewals	LC^R	0.1500	0.1500	0.1200	0.1200

Market NER growth ϵ in expansions and recessions comes from the January 2000 to December 2019 CompStak data.[13] NER is strongly pro-cyclical. Market NER growth in the remote work state comes from the December 2019 to December 2022 CompStak data. Market NER growth was -15.93% from December 2019 to December 2020 (one WFH-R year), and 1.94% per year from December 2020 to December 2022 (two WFH-E years).

Supply growth η incorporates new construction net of depreciation and reductions in office space due to conversion to alternative use. The values for supply growth for expansion and recession periods are calculated from CompStak based on the year of construction of all office buildings. New construction is 1.15% in expansions and 1.10% in recessions. We subtract a 2.56% depreciation rate from the new construction numbers to arrive at the net supply growth η reported in the table.[14] Supply growth is acyclical because of the long construction lags for office properties.

The values for supply growth in WFH-R and WFH-E periods are calculated by down-scaling E and R supply growth by a fixed amount $\Delta\eta$. The value for $\Delta\eta$ is set such that the model has long-run growth in potential gross rent of zero, given all other parameters, keeping the model stationary. The calibration has the intuitive feature that supply growth is substantially lower in the remote work states compared to the no-WFH states (1.5% per year). This captures the response of new construction to the reduced demand for office as well as increased conversion of office to alternative uses such as apartments.[15]

[13] When constructing market NER time series, we control for submarket, tenant industry, leasing type, and building class FEs and then apply 6-month moving average to the raw series. Since NBER business cycles in this period (and before) are shorter than commercial real estate leasing cycles, we use the latter to determine the values for annual NER growth in expansions and recessions. Strict adherence to NBER dates would result in office NER growth that is too similar across expansions and recessions, and make the large fluctuations in rent growth observed in the data highly unlikely events from the perspective of the model.

[14] Our depreciation estimate corresponds to the 39 years of allowable depreciation expense for non-residential commercial real estate assets for tax purposes.

[15] The amount of conversion of office to alternative use was de minimis prior to 2020, with fewer than 0.1% of the office stock converted each year between 1993 and 2020. Office conversions accelerated in starting in 2021. JLL projects they may reach 1% of the office stock in 2023. Conversions from office to residential use are difficult for physical, regulatory, and financial reasons

The parameters $s^O(E), s^O(R), s^V(E), s^V(R)$ govern office demand across the business cycle in the low-WFH state. We pin down these four parameters to match four moments of the NYC contractual occupancy rate over the period 1987.Q1–2019.Q4, plotted in panel B of Figure 2. Those moments are the mean, the standard deviation, the maximum, and the minimum. The resulting lease renewal share for existing leases that are up for renewal, s^O, is strongly pro-cyclical. The new leasing share for vacant space, s^V, is counter-cyclical, simply because there is much less vacant space available for lease in expansions. This calibration ensures that our model matches both the average vacancy rate of NYC office as well as the amplitude of the leasing cycle, which reflects cyclical tenant demand for office.

The parameters s^O and s^V in the high-WFH state are assumed to be proportional to their no-WFH counterparts:

$$s^i_{z,wfh} = \delta \cdot s^i_z, \qquad z = E, R, \quad i = O, V. \tag{6}$$

We estimate δ to best fit the dynamics of the office occupancy rate over the 15 quarters from 2020.Q1–2023.Q3. Appendix D explains the details. The resulting value is $\delta = 0.51$, which indicates a large downward shift in office demand in the high-WFH state. This shift is consistent with the evidence on the large decline in new leasing activity, documented in Figure A2.

Finally, the scaled fixed and variable costs are assumed to be acyclical. This makes net operating income (revenue minus cost) more cyclical than revenues, generating operational leverage. Leasing commissions are also acyclical, and around 4.3% per year on leases that last an average of 7 years, for a total commission of 30% on a new lease. Leasing commissions on renewals of existing leases are set half as large as commissions on new leases. Leasing commissions are assumed to go down by 20% in the WFH state to reflect additional competition for brokerage business in a world where office demand is weak.

3.3.4 Office Cash Flows for A+ Properties in NYC

Next, we calibrate the model to A+ buildings of New York City. We use the leases on the subset of A+ buildings to get parameter estimates for the A+ NYC office sector.[16] The calibration approach parallels that for All NYC, and is detailed in Appendix D. χ is set to be 0.12 to match the slightly higher average

(Gupta, Martinez and Van Nieuwerburgh, 2023).

[16]Specifically, we isolate leases that are in the top ten percent of the NER distribution in each quarter and submarket among all properties that are ranked as Class A by CompStak. We categorize a building that has such a lease as A+ and assume that the A+ status remains for ten years, unless another top-10% lease is signed in that building at which point the ten-year clock resets. By this definition, 34.0% of square feet and 41.0% of lease revenue is in A+ office buildings in New York City.

lease duration of 8.05 years of A+ leases in NYC. Appendix Table E1 lists the remaining parameter estimates for the A+ universe. The cost parameters are assumed to be the same as for NYC All.

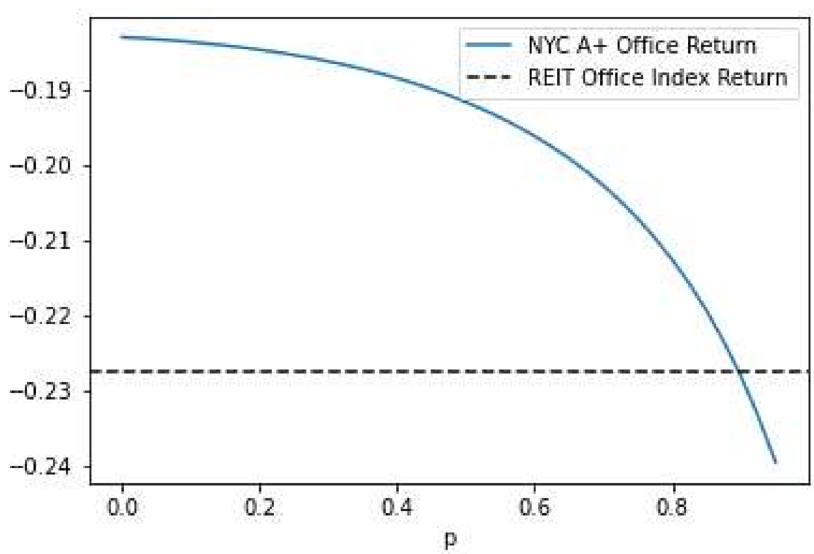
3.4 Identifying the Persistence of Work From Home

A key parameter in the calibration is p, which governs the persistence of remote work. We identify this parameter from REIT data as follows. We assume that the economy transitioned from the low-WFH expansion state (the E state) in 2019 to the high-WFH recession state (WFH-R) in 2020. We compute the model-implied return on the NYC A+ office market in this transition, using the A+ calibration:

$$\left(\frac{\widehat{V}^{A+}(\widehat{Q}^O_{20}, \widehat{R}^O_{20}, WFHR)}{\widehat{V}^{A+}(\widehat{Q}^O_{19}, \widehat{R}^O_{19}, E)}\right)\left(\frac{\overline{Q}_{20}R^m_{20}}{\overline{Q}_{19}R^m_{19}}\right) + \left(\frac{\widehat{NOI}^{A+}(\widehat{Q}^O_{20}, \widehat{R}^O_{20}, WFHR)}{\widehat{V}^{A+}(\widehat{Q}^O_{19}, \widehat{R}^O_{19}, E)}\right) = (1 - 22.75\%).$$

Figure 6 plots this model-implied realized return on A+ office in this transition, the left-hand side of the equation above, for a range of values of p.[17] Since the office return in this transition varies strongly and monotonically with p, this moment is well-suited to identify this parameter.

Figure 6: Determining **p** by Matching Realized Return of A+ Market



In order to pick the relevant point on this curve, we turn to the REIT data. REITS invest in class A+

[17] As the equation shows, this return depends also on $(\widehat{Q}^O_t, \widehat{R}^O_t)$ for 2019 and 2020, respectively. We obtain the values for these state variables by feeding in the sequence of annual aggregate shocks (E and R) from 1926 to 2019 obtained from the NBER recession chronology into the laws of motion of the states under the A+ calibration, delivering the 2019 values. For the 2020 values, we apply the law of motion for the state variables once more, assuming that the state transitioned from E to WFH-R.

office properties. The three NYC-centric office REITs, SL Green, Vornado, and Empire State Realty Trust, experienced a value-weighted stock return of -36.16% between December 2019 and December 2020. After delevering this equity return, the asset return was -22.75%.[18] The model matches this decline for a value of $p = 0.90$. With this key parameter identified, we can return to the calibration for the full NYC office market and calculate the change in its value due to remote work.[19]

4 Office Valuation Results

4.1 Key Model Outcomes

Table 3 presents the model solution for the “All NYC" office calibration. The model delivers a reasonable unconditional average cap rate of 8.00% for the overall NYC office market. The cap rate is 9.14% in recessions and 7.59% in expansions.[20]

In a Gordon Growth Model with constant expected NOI growth rate g and a constant discount rate r, the cap rate $c = r - g$. Our Markov Chain model features time-varying expected growth and time-varying expected office returns, so this relationship does not hold. It is nevertheless useful to look at the two components of the cap rate. The model implies an expected return on NYC office of 8.04% and an office risk premium of 7.50%. This is naturally lower than the equity risk premium of 10.54% since an unlevered office property is less risky that the aggregate stock market (which is a levered investment). The office risk premium is substantially higher in recessions (11.98%) than in expansions (6.61%).[21] Expected NOI growth is close to zero unconditionally. This number is in real terms and incorporates that the office stock depreciates, so that real NOI growth is 1.89% before depreciation (=-0.67%+2.56%). Expected cash flow growth is higher in recessions than in expansions since recession states imply a high likelihood of transitioning to a better economic state going forward. The opposite is true of *realized* NOI growth rates in a transition from expansions to recessions, which are negative in the

[18] Delevering is done based on leverage ratio and cost of debt data from NAREIT.

[19] We chose to calibrate to the full-year 2020 REIT return since the model is annual. Alternatively, one could use this calibration strategy to calibrate to the REIT return measured over at different periods. The observed office REIT returns were more negative when measured over a shorter period from February 2020–April 2020, and also when measured over the longer period from December 2019– December 2022. This makes our results conservative. One could also use our procedure to update the implied persistence parameter over time.

[20] The hedonic-adjusted cap rate for Manhattan Office averaged 5.3% over the period 2001–19 according to Real Capital Analytics data. The model predicts a 6.49% average cap rate for the same period. The discrepancy is mostly explained by the unusually low interest rates in the 2001–19 period. Longer data from CBRE put the average office cap rate for NYC at 7-8%, close to our model’s steady-state. Like the model, the Real Capital Analytics data indicates higher cap rates in recessions than in expansions.

[21] The model also has interesting implications for the term structure of office risk premia discussed in Appendix G1.

Table 3: Model Solution for NYC All Calibration

Statistic	Uncond	E	R	WFHE	WFHR
R_f	0.0054	-0.0012	0.0372	-0.0012	0.0372
Equity $\mathbb{E}[Ret]-1$	0.1109	0.0661	0.3193	0.0659	0.3190
Equity RP = $\mathbb{E}[Ret]-1-R_f$	0.1054	0.0673	0.2821	0.0671	0.2819
Cap rate	0.0800	0.0759	0.0914	0.0793	0.0998
Office $\mathbb{E}[Ret]-1$	0.0804	0.0650	0.1569	0.0644	0.1453
Office RP = $\mathbb{E}[Ret]-1-R_f$	0.0750	0.0661	0.1198	0.0656	0.1081
$\mathbb{E}[g_t]$	-0.0067	0.0217	-0.0231	-0.0447	-0.0695
Vacancy rate $= 1-\widehat{Q}^O$	0.1569	0.0948	0.1509	0.2619	0.2758
$\widehat{\text{Rev}}$	0.7965	0.8306	0.8098	0.7281	0.7604
$\widehat{\text{Cost}}$	0.3925	0.3987	0.3945	0.3778	0.3967
$\widehat{\text{NOI}} = \widehat{\text{Rev}} - \widehat{\text{Cost}}$	0.4041	0.4319	0.4154	0.3503	0.3636
$\widehat{V}^R$	10.1473	10.9666	10.0792	8.8215	8.5952
$\widehat{V}^C$	5.0908	5.4099	5.0057	4.6005	4.4863
$\widehat{V} = \widehat{V}^R - \widehat{V}^C$	5.0564	5.5567	5.0735	4.2210	4.1088

Notes: The calculation of equity market risk premium in the high-WFH state is detailed in Appendix D3.

model.

The next part of the table shows that vacancy rates are 15.7% on average, higher in recessions than expansions by 5.61% points, and much higher conditional on being (and remaining) in the remote work states, around 26.4%.

The last part of the table shows the value of the building, scaled by potential rent, and broken down into the PDV of revenues minus PDV of costs. The typical NYC office trades for a multiple of 5.06 times potential gross rent unconditionally according to our calibration. The average valuation ratio of office properties in the no-WFH expansion state of 5.56 is 35.24% higher than the value of 4.11 in the WFH-R state. Appendix Figure D1 shows the valuation ratio for office $\widehat{V}$ in each of the four aggregate states.

4.2 The Effect of WFH on Office Values

4.2.1 Entire Office Stock

To assess the effect of remote work on office values, we let the economy undergo the same transition as the one we considered for A+ office when calibrating the parameter p, namely from an expansion in the low-WFH state in 2019 to the WFH-R state in 2020. We feed in the observed history of expansions and recessions from 1926–2019 to arrive at the value for the endogenous state variables $(\widehat{Q}^O_{19}, \widehat{R}^O_{19})$ using the laws of motion for the states (2) and (3) under the "All NYC" calibration. The model captures the

decade-long expansion before 2020. We then apply the law of motion once more to obtain $(\widehat{Q}^O_{20}, \widehat{R}^O_{20})$ assuming the economy transitioned from E to WFH-R between 2019 and 2020.

The realized growth rate of potential gross rent in this transition is -18.42% in the model. The change in the scaled valuation ratio is -41.23%. Therefore, the overall value of the NYC office stock in this transition falls by 52.05%:

$$\left(\frac{\widehat{V}(\widehat{Q}^O_{20}, \widehat{R}^O_{20}, WFHR)}{\widehat{V}(\widehat{Q}^O_{19}, \widehat{R}^O_{19}, E)}\right)\left(\frac{\overline{Q}_{20}R^m_{20}}{\overline{Q}_{19}R^m_{19}}\right) = (1-41.23\%)\cdot(1-18.42\%) = (1-52.05\%).$$

Put differently, if the entire office stock of NYC had been marked-to-market, its value would have fallen by 52.05% over the course of 2020. This same decline is 28.24% for the A+ office sector, illustrating the relative safety of A+ office.

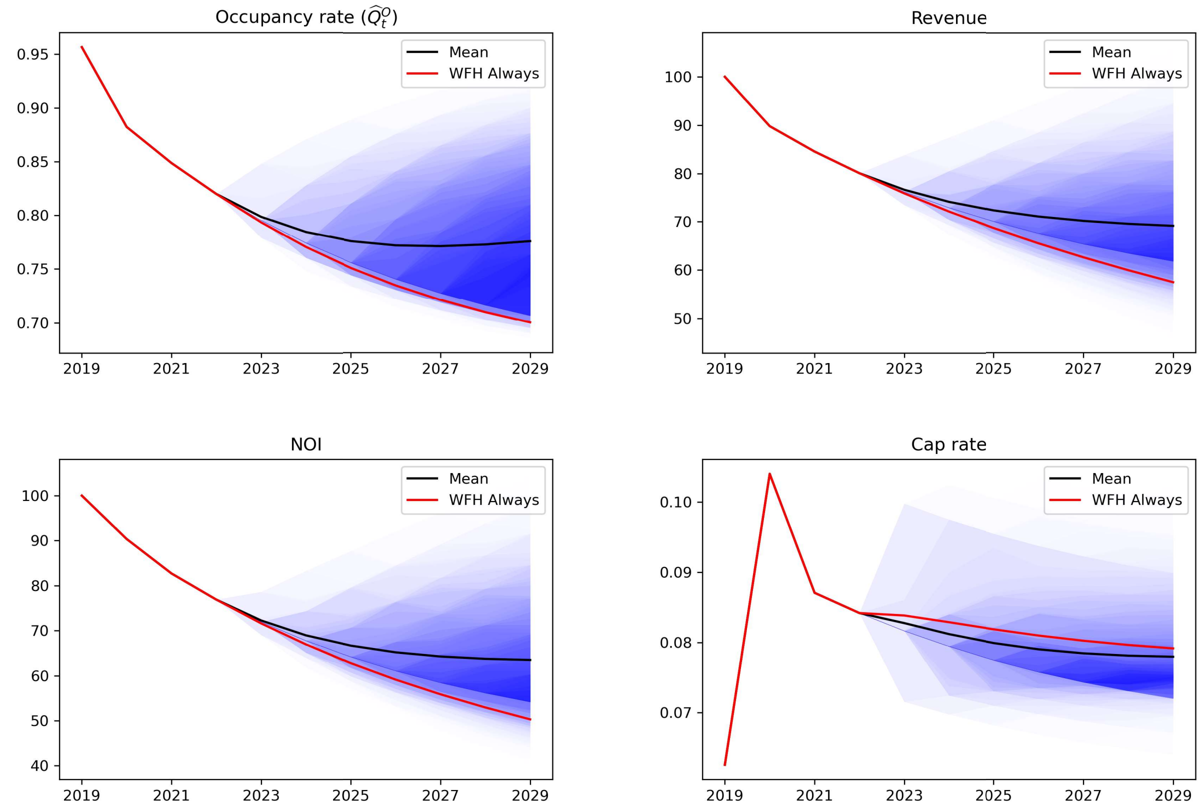
To understand the longer-run consequences of remote work, we conduct the following simulation exercise. In the first period of the transition, from 2019 to 2020, the economy goes from the E to the WFH-R state. In the second year, from 2020 to 2021, the economy transitions from WFH-R to WFH-E. In the third year (2022), it stays in the WFH-E state. From 2023 onward, we let the economy evolve stochastically according to its laws of motion governed by π. Since there are many possible paths for the evolution of the state, Figures 7 and 8 show fan charts where darker blue colors indicate more likely future paths. The solid black line indicates the mean path. The red line plots the mean path conditional on the economy remaining in the high-WFH state every year until (at least) 2029. The probability of this event occurring is 46.68% according to the model.

The top left panel of Figure 7 shows the occupancy rate dynamics from the model simulation. The model captures a substantial decline in occupancy from a high value of 95.65% in 2019 to a value of 81.99% in 2022. In the data, there is a similar decline from 88.9% in 2019.Q4 to 77.8% in 2022.Q4. Since long-term leases continue to roll off and renew at low rates as long as the economy remains in the high-WFH state, the decline in occupancy is protracted. Should the economy remain in the high-WFH state until 2029, occupancy would eventually fall below 70% even after accounting for the supply response.[22]

Lease revenues, in the top right panel, reflect the protracted decline in occupancy and the gradual repricing of existing leases at lower market rents. The model predicts a decline in active lease revenues ($Q^O R^O$) of 19.93% between 2019 and 2022, compared to the decline in active lease revenues in the CompStak data for New York City of 17.83% between December 2019 and May 2023. Lease revenues go down

[22] Recall that supply growth in the high-WFH state is 1.49% points lower per year than in the low-WFH states. This captures reduced construction as well as conversion of office to alternative use.

Figure 7: Key Moments Distributions



Notes: The graph shows the evolution of key model moments for a transition from expansion in 2019 to WFH-R in 2020, WFH-E in 2021 and 2022. From 2023 onward, the state evolves stochastically. Revenue and NOI are normalized to 100 in Dec 2019. The shaded areas show percentiles of the distribution of simulated paths, with the darkest color indicating the 49–50 percentile range, and the lightest color the 1–98 percentile range.

30.86% by 2029 along the average path. They fall by an additional 10% points for the red line, reflecting the larger vacancy rate, lower rents, and faster reduction in the quantity of office space if the economy remains in the high-WFH state for longer.

The bottom left panel shows that NOI falls by more than revenues since only variable costs decline in occupancy but not fixed costs. This is the operational leverage channel in action.

The bottom right panel shows that office cap rates were around 6.26% in 2019 in the model, after a decade-long expansion that increased occupancy and rents. Cap rates then increase in 2020, fall back in 2021 as the economy shifts from recession to expansion, and then gradually stabilize toward their unconditional mean of 8.00%.

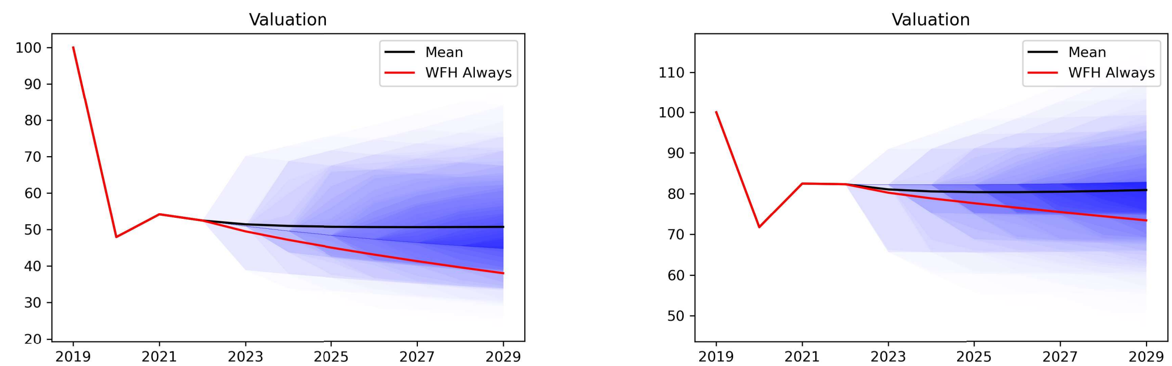
The combination of declining cash flows and rising cap rates results in a substantial change in the value of office V_t, shown in Panel A of Figure 8. The graph illustrates a mean path that sees no recovery. Remote work is a near-permanent shock. Ten years after the transition, office values remain at levels

that are 49.25% below the valuation in 2019. Along some sample paths, the economy returns to the low-WFH state and sees recovery in occupancy rates ($\widehat{Q}^O$), rent revenues, and NOI.[23] Along other sample paths, the economy remains in the high-WFH state (WFH-E or WFH-R) for a long period, and office valuations continue to fall. Conditioning on remaining in the WFH state for at least 10 years (red line), office valuation are 61.90% lower in 2029 than in 2019.

Figure 8: Office Valuation Distribution

Panel A: All NYC

Panel B: NYC A+ Buildings



Notes: The graph shows the evolution of the office value V for a transition from expansion in 2019 to WFH-R in 2020, WFH-E in 2021 and 2022. Values are normalized to 100 in Dec 2019. From 2023 onward, the state evolves stochastically. The shaded areas show percentiles of the distribution of simulated paths, with the darkest color indicating the 49–50 percentile range, and the lightest color the 1–98 percentile range. Panel A shows the distribution of values for all NYC office buildings; Panel B focuses on A+ office value (buildings with a lease in the top ten percentile of the rent distribution in their submarket in the last ten years).

A second key message from our valuation exercise is that there is substantial uncertainty around the mean path. This uncertainty results from medium-frequency fluctuations between recession and expansion as well as from lower-frequency uncertainty about the future evolution of remote work. Office valuations are subject to *WFH risk*.

4.2.2 Flight To Quality

The previous results referred to the entire NYC office stock. We do a separate valuation exercise for the A+ segment, which has its own cash-flow parameter calibration to the A+ data (as defined in Section 2). The resulting parameters and the model output for cap rates, valuation ratios, and vacancy rates are reported in Appendix E. They show lower unconditional cap rates and lower expected returns in the A+ segment, consistent with the lower risk of this segment.

Panel B of Figure 8 revisits the transition graph for office values. It shows substantially smaller value reductions both in the short- and in the long-run. The mean path has office values down by 19.10% in

[23]There is no full recovery since the first three years in the high-WFH state permanently reduce the size of the office stock.

2029 compared to 2019. In the scenario where the economy remains in the WFH state until at least 2029, the decline in A+ office values is 26.54%. The better performance is due to the stronger rent growth for A+ in the WFH states, and a lower risk premium for A+ office especially in the WFH state.

Conversely, the performance of the A-/B/C-class office segment is strictly worse than the overall market. Its initial value decline is -74.40% compared to -52.05% for all office.

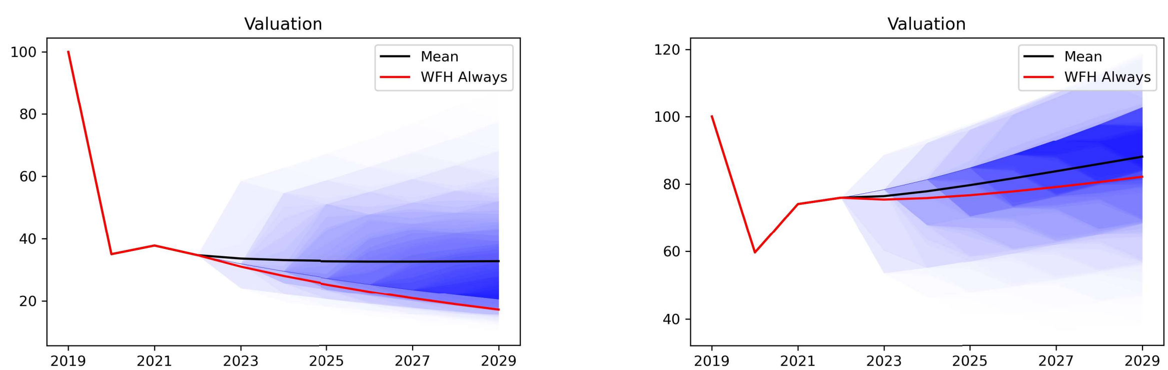
4.3 Other Office markets and Aggregate Impact

4.3.1 San Francisco and Charlotte

We repeat the valuation exercise for San Francisco (SF) and Charlotte. Appendix F discusses the calibration and reports the resulting valuation moments. Figure 9 below shows the main fan chart for the valuation of the stock of SF office (left panel) and Charlotte office (right panel). The short-run (long-run) declines in office values are 65.34% (67.09%) for SF and 24.04% (11.91%) for Charlotte. The former are larger than for NYC, due to the more cyclical nature of the SF office sector and its larger WFH exposure. This is consistent with SF's larger exposure to tenants from the technology sector who have more eagerly embraced remote work. Charlotte's valuation effects are smaller than NYC due to its milder office cycles and smaller exposure to the WFH shock. Adjusted for market coverage, the total office value destruction between the end of 2019 and 2022 is $31.3 billion in SF and $1.9 billion in Charlotte.

Figure 9: Office Valuation Changes for Other Cities

Panel A: San Francisco Panel B: Charlotte



Notes: The graph shows the evolution of the office value V for a transition from expansion in 2019 to WFH-R in 2020, WFH-E in 2021 and 2022. From 2023 onward, the state evolves stochastically. Office values are normalized to 100 in Dec 2019. The shaded areas show percentiles of the distribution of simulated paths, with the darkest color indicating the 49–50 percentile range, and the lightest color the 1–98 percentile range. Panel A shows results for San Francisco, and Panel B shows results for Charlotte.

4.3.2 Aggregate Impact

Table 4 compiles statistics on the top-20 U.S. office markets. It reports the quantity of active leases (in sf) in December 2019 (Column 1), the percent change in active lease revenue between December 2019 and December 2022 (Column 2), and the change in the quantity (Column 3) and in the NER (Column 4) of newly-signed leases over the same period. These statistics show that the decline in leasing activity is widespread. NYC is not an outlier. The bottom panel compares the top-20 office markets to all 105 office markets and shows similar changes in Columns 2–4.

Table 4: Cross-Sectional Results For Top 20 Markets

State	Market	(1) Active sf (mil)	(2) Lease Rev Chg (%)	(3) New sf Chg (%)	(4) NER Chg (%)	(5) Value Chg ($ Bil)	(6) Coverage (%)	(7) Value Chg Tot ($ Bil)	(8) Value Chg (%)
NY	New York	289.08	-14.68	-37.61	-5.00	-70.07	73.58	-95.23	-44.12
CA	San Francisco	61.66	-19.04	-38.88	-20.75	-19.44	62.14	-31.28	-59.28
NC	Charlotte	23.82	-6.69	-88.76	-13.51	-0.90	47.54	-1.89	-17.63
DC	Washington DC	88.89	-26.22	-56.49	-21.74	-18.38	98.81	-18.60	-51.68
CA	Los Angeles	72.12	-22.84	-55.00	-14.17	-13.36	42.83	-31.20	-49.46
MA	Boston	57.41	-12.76	-21.96	11.55	-11.38	35.33	-32.21	-42.86
IL	Chicago	90.38	-21.87	-66.77	-24.61	-8.47	43.25	-19.59	-48.83
WA	Seattle	41.10	-18.82	-81.25	-11.37	-5.73	36.10	-15.87	-46.83
GA	Atlanta	42.08	-14.87	-81.30	-23.14	-4.47	31.33	-14.27	-44.25
TX	Dallas	45.96	-19.10	-51.55	5.04	-4.74	26.60	-17.82	-47.02
CA	Orange County	39.30	-25.15	-57.83	-17.23	-5.10	47.36	-10.77	-50.98
CA	San Diego	29.39	-19.28	-79.26	7.22	-4.44	42.11	-10.54	-47.14
TX	Houston	42.16	-27.76	-15.76	-12.68	-4.66	28.63	-16.28	-52.69
VA	Arlington	26.03	-30.23	-48.14	-0.90	-4.75	36.10	-13.16	-54.31
CA	Palo Alto & Sunnyvale	22.45	-17.55	-76.41	-18.15	-3.86	11.39	-33.89	-46.00
CA	San Jose	14.95	-12.16	-0.32	-1.59	-3.51	36.10	-9.72	-42.47
TX	Austin	27.72	-15.88	-75.99	-3.47	-3.21	54.54	-5.89	-44.91
CO	Denver	28.94	-17.82	-77.35	-26.69	-2.81	29.78	-9.44	-46.18
PA	Philadelphia	26.32	-19.09	-73.39	-18.01	-2.70	23.24	-11.62	-47.01
NJ	North Jersey	17.52	-12.57	-34.07	-13.17	-2.17	18.29	-11.86	-42.74
Top 20 (Compstak)		1087.26	-17.95	-55.36	-10.95	-194.15	41.26	-411.13	-46.97
Other markets (Compstak)		943.58	-16.19	-72.15	-7.81	-91.32	36.10	-252.99	-45.11
U.S. (Compstak)		2030.84	-17.38	-64.62	-8.77	-285.47	38.87	**-664.12**	-46.36

Notes: The table reports the quantity of active leases pre-pandemic (in million sf), the change in active leasing revenue (in % of pre-pandemic leasing revenue), the change in newly signed leases (% of pre-pandemic newly signed sf), the change in the net effective rent per sf on newly-signed leases (in % of pre-pandemic market NER), and the change in valuation (in 2022 December dollars) for top 20 markets and for all 105 markets in CompStak combined (last two rows). Pre-pandemic active space in column (1) is calculated in December 2019. The changes in columns (2)-(4) are measured between December 2019 and December 2022. The value change in column (5) measures the change in the total value of office in dollars between the end of 2019 and the end of 2022. It combines the change in the value-to-revenue ratio over the first three years of the pandemic from the model calibration with the size of the market in column (1) and the drop in leasing revenue in column (2). The value changes for New York, San Francisco, and Charlotte in the top panel are based on full calibrations of the model to each of these cities separately, while the change in the valuation-to-revenue ratio for the other 17 top-20 markets in the middle panel is based on the New York City calibration. The aggregate numbers in columns (4) for the top-20 markets, other markets, and national NER changes are adjusted by industry, building class, submarket, and renewal FEs to remove composition effects. Column (6) is the CompStak coverage ratio, measured as the ratio of pre-pandemic active leased space in CompStak and active leased space in Cushman & Wakefield data. Column (7) divides column (5) by the coverage ratio in column (6). The last column reports the percentage change in the value between the end of 2019 and the end of 2022.

Column (5) calculates the change in office values between December 2019 and December 2022 (in December 2022 dollars). It combines the size of the market in column (1), the change in lease revenues reported in column (2), and the change in the value-to-revenue ratio from the model. For NYC, San Francisco, and Charlotte, we calibrated the model separately, delivering a valuation ratio change that is

market-specific. The three-year value destruction is \$70.1 billion for NYC, \$19.4 billion for San Francisco, and \$0.9 billion for Charlotte. For the other 17 large office markets, we use the market-specific size and leasing revenue change in columns (1) and (2) and combine them with the valuation-to-revenue ratio change for NYC to arrive at column (5). Summed across the top-20 markets, we obtain a \$194.2 billion value loss. Extending the analysis to the remaining 85 office markets, we find an additional \$91.3 billion in value destruction for a total of \$285.5 billion across all 105 markets in the CompStak data.

CompStak does not provide universal coverage. Based on Cushman and Wakefield reports, we are able to obtain a December 2019 coverage ratio estimate for 18 of the top-20 markets, shown in column (6). A coverage ratio of 36.1% for the remaining 87 markets (=105-18) reconciles the total U.S. office inventory in CompStak to that in Cushman & Wakefield. To obtain our aggregate value impact statistic in column (7), we divide column (5) by column (6). We arrive at an aggregate \$664.1 billion loss in office values nationwide over the 2019–2022 period. The largest dollar losses are in NYC (\$95.2 billion), Boston (\$32.2 billion), Los Angeles (\$31.2 billion), San Francisco (\$31.3 billion) and Palo Alto & Sunnyvale (\$33.9 billion). Relative to the pre-pandemic valuation, the U.S. office stock lost 46% of value by the end of 2022, as indicated in Column 8.

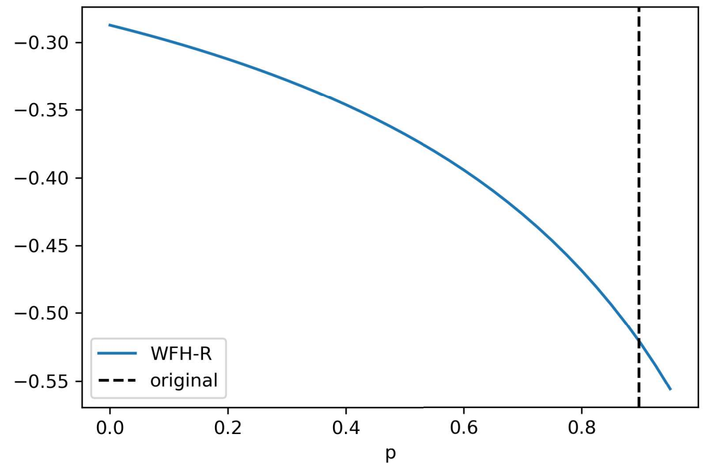
4.4 Sensitivity Analysis

We conduct several robustness checks. First we explore sensitivity to the WFH persistence parameter p. Figure 10 plots the NYC office value decline in 2020. The vertical dashed line indicates our benchmark model with $\mathbf{p} = 0.90$, which produces a 52.05% valuation decline in the transition. This same decline is 35.67% for a value of p that is half as large as our benchmark.

Next, we study sensitivity to another important parameter: market NER growth in the WFH-R state. That parameter is hard to pin down since we have only observed one realization of that state. Figure G2 shows that setting NER growth in the WFH-R state equal to that in the R state, a natural alternative calibration, has only minimal effect on office values compared to the benchmark. This result suggests that our results are not crucially driven by poor office realizations in 2020.

The transition to the WFH state affects office values through both cash flow and discount rate channels. We conduct an exercise where we shut off the WFH discount rate channel by setting M^{WFH} equal to the identity matrix. Figure G3 shows that the office value decline is only modestly smaller (-44.8% in 2029 vs -49.2% in the benchmark model), so that 90% the valuation impact comes from lower current and future cash flows and priced business cycle risk.

Figure 10: Change in Valuation with Different p for All NYC



Finally, Figure G4 performs four sensitivity analyses for San Francisco office values to (i) rent growth in the WFH-E state, (ii) the reduction in supply growth in the WFH states, (iii) the persistence of remote work, and (iv) the introduction a floor for office values as a simple way to model optionality arising from adaptive reuse (not already captured by the net supply parameter η). The persistence parameter and the supply gap have the largest impact on valuations.

5 Discussion and Conclusion

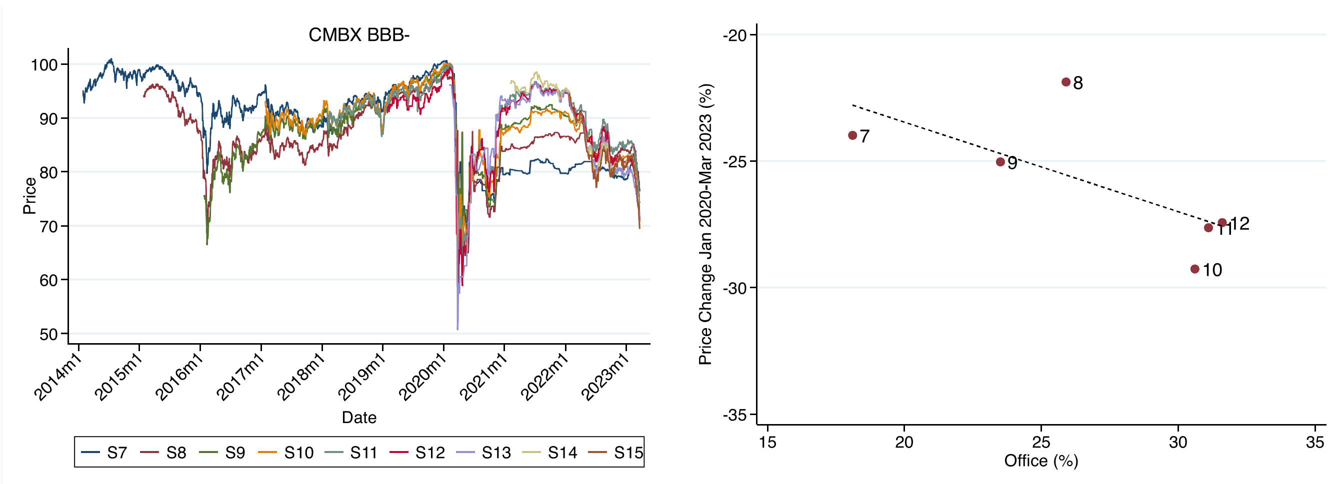
The real estate sector provides a unique vantage point to study the large social shifts in the wake of the Covid-19 pandemic, notably working from home. We estimate a 52.0% decline in the value of New York City's office stock since the start of 2020. We estimate that remote work is likely to persist and result in long-run office valuations that are 49.2% below pre-pandemic levels. The numbers for NYC are not an outlier; we find similar effects across many of the largest office markets. Our novel commercial real estate valuation model is suitable for calibration to office markets in other locations, other commercial real estate sectors, and other real assets.

These valuation changes are large, but since about 80% of the office stock is privately-held and private transactions have been few and far between (and represent a heavily selected sample), it has been difficult to directly observe the valuation changes in the market place. One exception is office REIT stocks, whose (unlevered) valuations the model matches both in 2020 and in 2022. In 2023, as more leases have come up for renewal and mortgages have reached their maturity, distress has begun to ma-

terialize. Distressed sale prices are in line with the model's predictions.

Other market indicators that have turned bearish are short interest (as a share of equity float) in office REIT stocks and the prices of CMBX tranches rated BBB-. Specifically, tranches in more recent CMBX vintages, which have a larger share of office collateral than earlier vintages, have experienced larger price declines, as shown in Figure 11.

Figure 11: Price of CMBX Insurance and Office Exposure



Panel A: CMBX Prices

Panel B: Office Exposure

Notes: Panel A shows prices for the Markit CMBX index of credit default insurance for BBB- tranches. A price of \$60 implies that a pool without early prepayments or defaults requires an upfront payment of roughly \$40 per \$100 original notional to initiate a trade purchasing protection against default. The different lines are for different vintages, denoted S7 through S15. Panel B plots the share of mortgages in each vintage that is backed by office properties against the price change of the CBMX BBB- tranche between January 2020 and March 2023.

The predicted decrease in office values, particularly for lower-quality offices, would impact not only the equity holders but also the debt holders under a standard pre-pandemic capital structure.[24] As depicted in the right panel of Figure 12, equity ownership of office properties is widely spread among various investor types. Debt ownership, shown in the left panel, is more concentrated with banks holding over 60% of all CRE debt.

A large proportion of banks' assets is comprised of commercial real estate loans. Figure 13 shows that this particularly true for medium-sized banks (Table A3 gives more detail). CRE credit risk compounds the negative impact of higher interest rates on bank equity, increasing the risk of financial fragility especially among regional banks (see also Jiang, Matvos, Piskorski and Seru, 2023, for recent work on this important topic).

Finally, the decline in office values and the surrounding urban retail properties, whose lease revenues

[24] The typical commercial property is financed with around 2/3 debt (with little or no amortization) and 1/3 equity, so that a 50% loss in asset value (since loan origination) would result in a 100% loss in equity value and a 25% loss in debt value.